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BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Laser Applications in NASA Space Programs Case 900

DATE: March 4, 1968

FROM: R. K. Chen

MEMORANDUM FOR FILE

To date the use of lasers in space programs has been highly experimental. Two categories of applications have been attempted, ranging and voice communication. The ranging systems have been more successful and are being continued. The single voice communication experiment failed to achieve its objectives.

Laser Ranging Experiments

Laser ranging experiments were carried by four Explorer Satellites: Explorer 22 (Beacon-Explorer-B) launched on October 10, 1964; Explorer 27 (Beacon-Explorer-C) launched on April 29, 1965; Explorer 29 (GEOS-A) launched on November 6, 1965; and Explorer 36 (GEOS-B) launched on January 11, 1968. All of these satellites carried optical retro-directive corner reflectors to reflect laser beams originated from a ground station. The range measurements are obtained by measuring the time lapse between the transmitted and received laser pulses. Descriptions of the laser ranging experiments for the Explorer 22 and Explorer 29 missions are attached; this information was extracted from NASA news releases (Attachment 1 and 2). A more detailed description of these experiments and some results of the tracking experiments with the Explorer 27 and Explorer 29 spacecraft appeared in the November 1967 issue of IEEE Journal of Quantum Electronics. The titles and authors of applicable papers are:

1. "A Laser Satellite Ranging System - Part I: Equipment Design," by T. S. Johnson, H. H. Plotkin, and P. L. Spadin.

2. "A Laser Satellite Ranging System - Par II: Analysis of the GSFC Laser Ranging Data," by S. J. Moss and W. T. Wells.

Recently, an earth-moon laser experiment was conducted using the Surveyor 7 spacecraft which is on the lunar surface. Several Earth based laser sources were aimed at the Surveyor 7

(NASA-CR-94047) LASER APPLICATIONS IN NASA SPACE PROGRAMS (Bellcomm, Inc.) 17 p

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with its television camera aimed in turn at the Earth. The video information from the Surveyor television system was then transmitted to Earth via its regular microwave communication system. The description of the experiment, from a NASA news release, and a photograph of the image taken by the Surveyor television camera are attached as Attachment 3. A more descriptive article of the experiment appeared in the January 22, 1968 issue of the New York Times and is also attached as Attachment 4.

Voice Communications Experiment

A laser voice communication experiment was carried on the Gemini VII spacecraft. Three ground stations located at White Sands, New Mexico, Ascension Island, and the Hawaiian Islands, were implemented for conducting the experiment. Briefly, an Argon laser beacon was aimed at the orbiting Gemini Spacecraft by slaving the laser telescope to a C-band radar at the same site. The astronaut onboard the spacecraft was to seek visually the beacon signal by sighting through a telescope which was boresighted to the spacecraft laser transmitter. Upon receiving the beacon signal, the astronaut was to either send a 100 pulses per second data train or an 8,000 pulses persecond signal which was capable of conveying audio back to the ground station. The laser transmitter on the spacecraft consisted of an array of four gallium arsenide diode lasers with a total peak power of 20 watts; the modulation method used was pulse frequency modulation.

With the exception of sighting the ground transmitted beacon signal by the astronaut, the experiment was not successful.

The failure was the result of:

1. The change in Gemini VII flight plan which eliminated the desired ground coverage from White Sands. This station was planned as the primary experiment station and was equipped with the best instrumentation.

2. Ground equipment failure at the Ascension and Hawaii stations.

3. Bad weather conditions over some of the stations during some spacecraft passages.

An excerpt of this experiment taken from the official NASA Gemini VII Post-Mission Report is attached as Attachment 5.

R. K. Chen

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Attachments 1-5

extracted from:

NASA Release No: 65-333 Dated Oct. 29, 1965

Project: Geodetic Explorer-A (GEOS-A)
Subsequently designated as Explorer 29

Laser Corner Reflectors

Quartz-cube corner reflectors, or prisms, on the satellite will be used for optically measuring the satellite range and angle.

The 322 cubes, mounted on fiberglass panels, will reflect pulsed beams of light directed at the satellite by ground laser transmitters when the satellite is within range. Reflected light can be picked up by a ground telescope and amplified by a photomutiplier tube that converts the optical impulses to an electrical signal. A digital counter will record the time at which the beam of light is returned to the ground.

Another system photographs the reflected laser pulse against the stellar background.

Total travel time of the light pulses, from ground to satellite and back to the ground, is a measure of the distance to the satellite and thus forms the basis of the satellite optical laser tracking system being developed by NASA Goddard Space Flight Center.

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Attachment 2

extratted from:

NASA Release No: 64-237 Dated: Oct. 4, 1964

Project: Beacon Explorer-B (BE-B)
Subsequently designated as Explorer 22

THE LASER EXPERIMENT

The Beacon Explorer will carry a 10-pound array of fused silica glass reflectors designed to return back to Earth light signals aimed at it from a laser transmitter.

Mounted on the satellite's body are 360 one-inch glass prisms called "cube-corner" reflectors. These are constructed in such a way that light striking them from almost any angle will be returned to its source. They are arranged in the form of an eight-sided truncated pyramid, designed and built by General Electric Space Technology Center.

In one of the experiments, a laser unit mounted on an 18-inch diameter optical telescope housed in a 60-foot high tower located 20 miles south of NASA's Wallops Station, Va., will direct a pulsing beam of red light toward the satellite.

Goddard experimenters plan to attempt the first illumination of the satellite reflectors during the early nighttime passes over Wallops Island.

-more-

The planned orbital altitude of about 575 miles will place the Beacon Explorer at a typical slant range of approximately 1,000 miles when it appears, by reflected sunlight, as a star of about the ninth magnitude--20 times fainter than a star which can be seen by the naked eye.

The laser system is mounted on an IGOR (Intercept Ground Optical Recorder) telescope normally used by Wallops to track sounding rockets. Operators will aim the telescope along the predicted path of the Beacon Explorer and when they locate it, they will "flash" the laser light at a rate of one flash per second.

If all goes according to plan, the reflector array will be illuminated and will return a small portion of the light energy to the telescope. The reflected signal will be automatically amplified by a photomultiplier tube (a device that converts optical impulses to electrical signals). A digital counter will record how long it took for the light signal to go and come back.

In the event of overcast or inclement weather, illumination attempts will be delayed until optical sightings are possible.

-more-

The measurements of time between initiation of the light signal and reception at the photomultiplier will give the precise distance of the satellite for each second of time. These values will be recorded at the telescope site and later sent to Goddard where they will be compared with distances calculated from other tracking instruments, such as NASA's Space Tracking and Data Acquisition Network (STADAN).

These optical distance measurements are expected to be more precise than those obtained through other tracking procedures and may be used to define the Beacon Explorer satellite orbit more accurately. Other laser tracking experiments will be performed on telescopes near Goddard, over a period of several months after launch.

Results of the experiments may lead to a more definite determination of the Earth's shape and development of improved systems for future optical tracking and communications.

The laser system employs a six-inch synthetic ruby rod which becomes highly energized as it gathers light energy from a xenon gas-filled flash-lamp mounted closely paralled to it in a barrel-like metal and glass housing. The rod is designed so that both ends are polished to act like mirrors. The white light from the flash-lamp excites chromium atoms within the ruby rod which then re-emit light of a uniform color.

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As this red light is reflected back and forth inside the rod, the bouncing rays hit other excited chromium atoms and "stimulate" them to give off more red rays. It is from this stimulated emission that the laser (light amplification through the stimulated emission of radiation) gets its name. These rays are in phase with each other and are parallel to each other as they bounce back and forth between the reflecting rod ends. Scientists term this "coherent" light, in contrast with random sources having diffuse characteristics such as the Sun, electrical and neon gas lamps.

Within a fraction of a millionth of a second this chain reaction builds to a powerful beam that "bursts" out one end of the rod which has been made more transparent than the other. The laser light can be directed into a narrow pencil beam which does not lose its effective strength before reaching the target.

NEWS NASA NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546
TELS. WO 2-4155
WO 3-6925

RELEASE: IMMEDIATE
January 17, 1968
JAN 2_ 1968

RELEASE NO: 68-13

LASER BEAMS CHECK AIMING METHODS

Earthbound scientists will be directing their laser beams this week toward the landing site of Surveyor VII on the Moon to check their aiming methods for later Apollo experiments.

The television camera aboard the Surveyor spacecraft will be used in attempts to photograph the "squeezed" beams of light which can be directed from any one of a series of six Earth stations.

Tests are planned on the nights of Jan. 18, 19 and 20. Preliminary exercises were held Jan. 12 and 13. Surveyor VII was successfully landed on the Moon Jan. 7 by the National Aeronautics and Space Administration.

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Lasers at these Earth stations throughout the country are coupled to various types of telescopes. The green argon ion laser beams they direct at the Moon will be only a few miles wide, at the lunar distance of a quarter-million miles.

Factors beyond the control of scientists on Earth such as glare from the Sun entering the camera on the Moon, and twinkling caused by atmospheric turbulence on Earth may make detection difficult. The photos would then be processed by an enhancement technique like that used last year on the Mars photos taken by Mariner IV.

If these engineering tests prove successful they will help scientists evaluate their technique for aiming laser beams at objects in space. The tests are considered a prelude to an Apollo experiment to measure the distance between Earth points and an optical retro-reflector array on the Moon. The scheme would afford a precision not now available.

Prof. C. O. Alley of the University of Maryland's Department of Physics and Astronomy, is principal investigator, assisted by Prof. Douglas Currie, of the same university.

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Other scientists involved and their locations are Prof. S. K. Poultney, University of Maryland, and Dr. James Brault, Kitt Peak National Observatory, at the McMath Solar Telescope, Tucson, Ariz.; Prof. James Faller, Wesleyan University, Middletown, Conn., at the Raytheon Research Laboratory, Waltham, Mass.; Dr. Henry Plotkin, at NASA's Goddard Space Flight Center, Greenbelt, Md.; Drs. Robert Kingston and Hoyt Bostick, at Lincoln Laboratory, Cambridge, Mass.; Michael Shumate at Table Mountain Observatory, Brightwood, Calif., and a group from the Perkin-Elmer Corp., at Norwalk, Conn.

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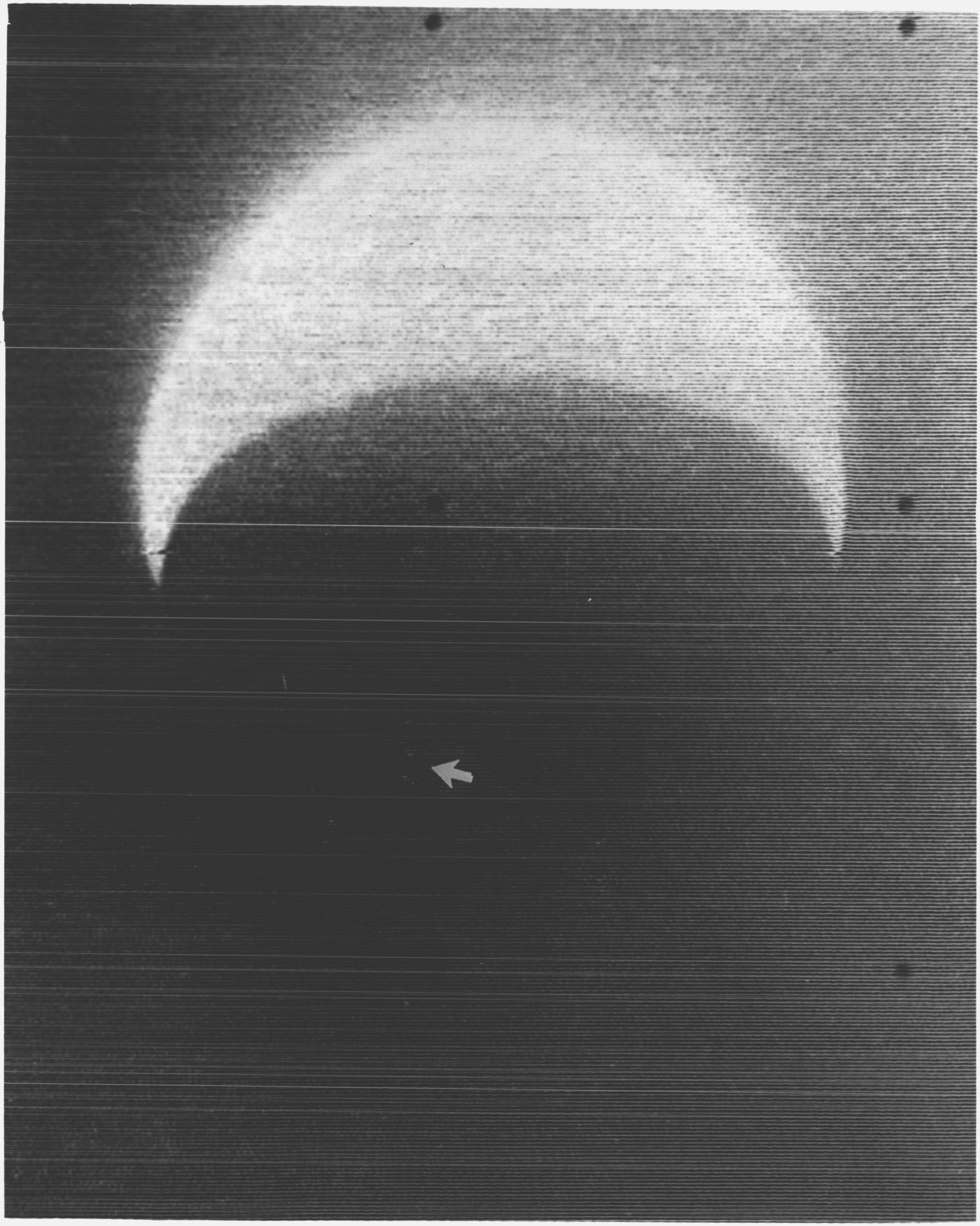

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

FOR RELEASE: January 23, 1968 -- IMMEDIATE

PHOTO NO. 68-H-80

Washington -- Laser beams aimed toward the landing site of Surveyor VII are shown as they were monitored Jan. 20, 1968, by the television camera aboard the NASA spacecraft and relayed back to Earth. The originating points of the laser beams, at Kitt Peak National Observatory in Tucson, Arizona (right) and Table Mountain Observatory at Wrightwood, Cal., (left) are indicated by the arrow on the dark side of the Earth. The Earth, as seen from the Moon by Surveyor VII appears as a crescent, with the illuminated portion to the right. The laser beams directed from Earth to the Moon were photographed by the National Aeronautics and Space Administration's Surveyor VII's camera and the picture transmitted back to Earth.

PHOTO CREDIT: NASA or National Aeronautics and Space Administration

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
400 MARYLAND AVENUE, S.W. WASHINGTON, D.C. 20546

FOR RELEASE: January 23, 1968 - IMMEDIATE

PHOTO NO. 68-H-50

Washington -- Laser beams aimed toward the landing site of Surveyor VII are shown as they were monitored Jan. 20, 1968, by the television camera aboard the NASA spacecraft and relayed back to Earth. The originating points of the laser beams, at Kitt Peak National Observatory in Tucson, Arizona (right); and Table Mountain Observatory at Wrightwood, Cal., (left); are indicated by the arrow on the dark side of the Earth. The Earth as seen from the Moon by Surveyor VII appears as a crescent, with the illuminated portion to the right. The laser beams directed from Earth to the Moon were photographed by the National Aeronautics and Space Administration's Surveyor VII's camera and the picture transmitted back to Earth.

PHOTO CREDIT - NASA or National Aeronautics and Space Administration

NEW YORK TIMES, 1/22/68

Surveyor 7 Again Relays Back Images of Earth Beams Taken From Moon

By EVERT CLARK

Special to The New York Times

WASHINGTON, Jan. 21—The Surveyor 7 spacecraft on the moon again photographed two laser beams from the earth today.

The lights were flashed from two mountaintops in the western United States, just as they were in the first test 24 hours earlier.

But the images photographed by Surveyor and relayed back to California by radio today were sharper than those in the first test.

This is the first use of light to communicate over such a great distance—almost 240,000 miles to Surveyor's site near the prominent crater Tycho, on the moon's southern face.

All previous communication with distant spacecraft has been by radio waves.

The laser tests are considered highly significant for the future use of lasers in civilian and military communications and measurement in space and on earth.

Prof. C. O. Alley of the University of Maryland, the principal experimenter, said in Pasadena that the moon's distance could now be measured to an accuracy of six inches by the precision light beams, a greater accuracy than that achieved by radar.

Apollo astronauts will mount reflectors on the lunar module that drops them on the moon's surface. Then Professor Alley's group will try to pinpoint the spaceship's location by beaming lasers at the reflectors.

Benjamin Milwitzky, Surveyor program director for the National Aeronautics and Space Administration, said that the tests "demonstrated the feasibility of a really revolutionary technology and made all kinds of revolutionary applications of it seem possible."

"We have also proved that the experiment definitely is repeatable," he said.

Little Power Used

The beams picked up by the Surveyor camera's small mirror came from the Kitt Peak National Observatory near Tucson, Ariz., and the Table Mountain Observatory near Brightwood, Calif.

Surveyor failed to see lasers from four Eastern sites, partly because of weather and partly because their locations were less favorable at the time.

Three to four watts of power was used by each laser—about that in a bedroom night light.

But lasers focus light rays so intensely that they can push the rays vast distances. Lasers also can pack millions of bits of information into a light beam, offering great promise for communications in space, where dust and moisture do not scatter the beam as they do in the atmosphere.

Space agency scientists and Professor Alley's group were greatly pleased with their success. The tests were intended only to help perfect aiming and transmission techniques for the later Apollo experiment.

The chances of success were once considered marginal and the tests had a low priority. Surveyor 7 is busy photographing the rough nearby terrain, digging the soil with a clawlike device and sampling the soil's mineral content.

The laser experimenters were allotted a few 10-minute periods to beam the lights toward Surveyor. The beams are about two inches wide at the earth. They spread out to several miles at the distance of the moon. The beams from an ordinary searchlight would be dissipated by the atmosphere after a few miles.

At one time scientists at the California Institute of Technology's Jet Propulsion Laboratory in Pasadena, which directs Surveyor work, thought the lasers might have been photographed early Friday morning. But the results were inconclusive.

When the beams appeared to have been photographed early yesterday, Professor Alley flew from here to the laboratory to examine the pictures.

Late last night word came from Pasadena that the experiment had indeed been a success. Professor Alley stayed in California for this morning's repeat performance.

Surveyor 7 has returned about 17,000 photographs since it landed on Jan. 9, bringing the total for five Surveyors to about 83,000 pictures of the moon.

8.14 EXPERIMENT MSC-4, OPTICAL COMMUNICATIONS

8.14.1 Objective

The objectives of experiment MSC-4 were to evaluate an optical communications system, to evaluate the flight crew as a pointing element, and to probe the atmosphere using an optical coherent radiator outside the atmosphere.

8.14.2 Equipment

The experiment equipment consisted of a gallium-arsenide laser transmitter (flight hardware), and three instrumented ground sites, each equipped with a flashing beacon and capable of collecting and demodulating coded optical signals.

The flight laser transmitter was a small, self-contained unit whose dimensions were 8.5 in. by 5 in. by 3 in. It produced 16 watts of optical coherent power in short bursts that were coded in a manner similar to a home movie camera. Special infrared safety (spectral) glasses and a microphone were attached to the unit. A 6-power telescope in conjunction with a 400-angstrom filter for fine tracking of the ground beacon was integral to the unit.

The three ground sites specially instrumented for this equipment were located at the White Sands Missile Range, New Mexico; at Kauai Island, Hawaii; and at Ascension Island in the south Atlantic Ocean. Each site operated in the same way. Each employed an argon laser as an optical beacon, each used large collecting telescopes, and each slaved its telescope mount to an orbital-track radar. The sites had instrumentation adequate for voice processing and determination of high-frequency atmospheric effects.

8.14.3 Procedure

Both of the flight crew members were given preflight beacon tracking experience in the docking simulator room and experience in sighting the unit in a field situation. Data recorded on a spacecraft test were to be complemented with static and aircraft fly-by field tests in an effort to isolate all deleterious parameters affecting the data and to determine a method of eliminating them. The ultimate goal is to identify atmospheric properties affecting the equipment and to provide mathematical models for future design efforts.

8.14.4 Results

Unfavorable cloud conditions hampering this experiment throughout the Gemini VII mission forced cancellation of all but four attempts. The ground beacon was observed by the crew only twice in these four attempts and this was for short intervals. No solid track could be accomplished by the crew in these short intervals, and no data were recorded. The following paragraphs describe the four attempts.

Revolution 79 over Hawaii – Even though cloud cover in the general area was favorable, the ground beacon site was obscured by a cloud.

Revolution 105 over Hawaii – The crew saw the ground beacon for about 20 seconds. However, the beacon came in and out of view. After the pass, it was determined that a slaving data-corrector package at the ground site was not operating properly and did not allow close tracking of the spacecraft.

Revolution 104 over White Sands – An equipment failure and complications with safety procedures delayed boresighting of the beacon with the radar, and only a coarse boresight was accomplished. After the pass, it was determined that the boresight was off by 3 beam widths.

Revolution 119 over White Sands – The crew observed the beacon for 2 or 3 seconds twice during the pass. After the pass it was determined that reversed stator leads on the ground caused a poor track.

The argon lasers used as ground beacons caused severe problems at the Hawaii and Ascension stations. The same type of laser had worked well at White Sands during the Gemini V mission, and, in fact, worked well during the Gemini VII mission. The Ascension Island station was not able to get a laser to operate beyond boresighting.

The problems encountered with this experiment were corrected in the field with the exception of the laser deterioration. This problem has been relieved by equipment modifications, but it is not fully resolved.

8.14.5 Conclusions

Experiment MSC-4 did not achieve any of the stated objectives. However, the information gained does indicate the following:

(a) Beacon lasers with greater adaptability to different environments are needed.

(b) A 1-watt argon gas laser is visible at orbital altitudes.

(c) The green filter in front of the spacecraft acquisition and tracking telescope hinders acquisition of the beacon.

(d) Very close inspection of the beacon-telescope mount and tracking-radar mechanism must be maintained on a day-to-day basis to insure the necessary close track of the spacecraft.

The Gemini VII crew has recommended that a laser site be placed in an area that is more easily acquired, such as Cape Kennedy.

Although the experiment was not successful on the Gemini VII mission, the major system parts have been proven. The laser beacon was shown to be visible at orbital altitudes, static tests have shown that adequate signal-to-noise ratios can be obtained, and previous aircraft fly-bys have indicated that the system can track to within the required accuracy when the system is functioning properly.

BELLCOMM, INC.

Subject: Laser Applications in NASA Space Programs

From: R. K. Chen

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